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UNDERWATER RADIO ELECTRONICS

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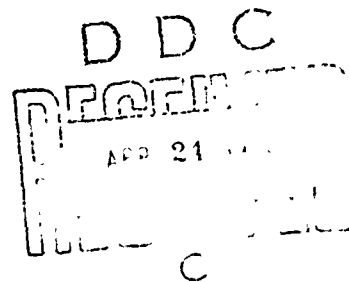
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## UNDERWATER RADIO ELECTRONICS

(An. Sergeyev. Radioelektronika pod Vodoy, Publishing House "Energiya", Leningrad Branch, 1971, pages 2; 75-80; 84-106; 125-140; 141-142; Russian)

This booklet acquaints the reader with one of the important areas of radio electronics, hydroacoustics, which is based on the utilization of the acoustic wave propagation phenomenon in water. The book considers the main characteristic features of sound wave propagation in oceans and seas and discusses the principle of operation and construction of acoustic antennas and other hydroacoustic equipment components.

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The reader will learn the principles of operation and construction of the most important hydroacoustic equipments used in the solution of various problems related to man's activities at sea depths, such as active and passive sonars, communication devices, fish finders, and navigation equipment.

The book is intended for a wide circle of readers such as radio amateurs and all persons interested in the present state of the art of various types of radio electronic equipment.

Lately, the method of measuring range using continuous radiation of signals and frequency modulation is used more and more. In this method, the sonar radiates oscillations whose frequency changes follow a saw-tooth pattern (Fig. 32).

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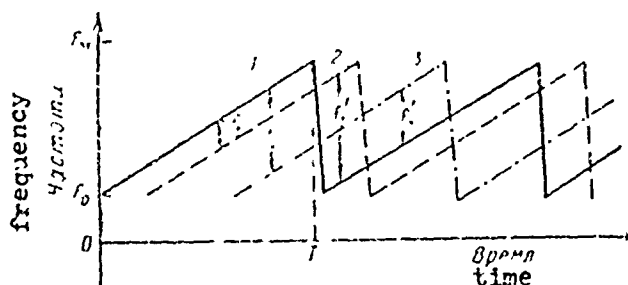


Fig. 32. Measuring range using continuous signals and frequency modulation 1 - radiated signal; 2, 3 - echo signals.

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\*Numbers in the right margin indicate pagination in the original text.

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Upon reaching the target, these oscillations return to the transmit-receive point in the form of echo signals with a frequency different from that transmitted during the echo signal reception by a certain value ( $\Delta f_R$ ). This value depends on the distance to the target and it increases with an increase in this distance. The modulation frequency parameters of the transmitted signal are selected so that the sound signal can pass the distance equal to or greater than the maximum operating range of the sonar during the modulation period. During this period, the transmitted signal frequency will change by a value of  $\Delta F$  which is the frequency deviation.

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If, during target ranging, the difference between the instantaneous transmission and reception frequencies is  $\Delta f_R$ , then the target range may be found by the following expression  $R = R_{\max} (\Delta f_R / \Delta F)$ . The difference in frequency will change with the change in target range so that with an increase in range it will increase and with a decrease in range it will decrease. This simple relationship makes the method suitable for use in small size devices such as sonars used by divers, for example. By observing changes in the sound pitch, the diver would be able to know his position relative to the underwater object under study. In this case, use of complex indicators is not required. One may expect that the method will also be used in amateur equipment.

For target ranging by means of the more complex shipboard equipment, a set of band-pass filters is used. Each filter passes a frequency difference which corresponds to a certain range. By means of an electronic switch, sequential interrogation of all filter outputs is carried out. The target range is determined by noting the filter which passes the signal. Lights which are switched on by means of threshold devices that are included in the filter circuits may serve as signal indicators. In certain cases switching of filter outputs is accompanied by the simultaneous beam scanning on the CRT screen. Scanning begins with the interrogation of that filter which corresponds to a minimum range and ends after the interrogation of the last filter. If a signal is received during the interrogation, the position of its marker on the scanning line will correspond to the target range. The accuracy of measuring range is governed by the number of filters used. Thus, even with the use of 50 filters, the maximal error of measuring range does not exceed 1% of the full scale.

Theoretical principles considered in the preceding chapters were used as a basis for production of various hydroacoustic devices.

These devices are used in observations and communication under water, for insuring safe navigation, for finding fish and sea animals, for carrying out various biological investigations, for studying the composition of the sea bed, for mineral prospecting, and in many other areas. The hydroacoustic technology finds the ever wider use in the underwater sport and boating. The amateur hydroacoustic equipment is already available. Let us consider the construction and operation of the main modern hydroacoustic equipment.

## 22. Hydroacoustic Equipment Range.

In order to understand certain peculiarities in the construction and operation of the hydroacoustic equipment, let us acquaint ourselves with the main factors which govern the operating range of the equipment. It was mentioned earlier that acoustic signals are received against the background of the intense reverberation and noise of various origin.

For separating signals from noise, it is necessary to have the following relationship between their intensities ( $I_s$  and  $I_n$ ):

$$I_s \geq \delta I_n \quad (1)$$

where  $\delta$  is the so-called threshold coefficient.

$$\text{In sonar} \quad \delta \approx \frac{1}{V_{\Delta f T}} \quad (2)$$

where  $k_g$  is the recognition coefficient which characterizes the required signal-to-noise ratio at the indicator input which makes it possible to receive signals with a given probability;  $\Delta f$  is the passband of the receiving channel; and  $T$  is time used in signal averaging.

The sonar signal intensity may be expressed as

$$I_s = \frac{\omega_a \gamma_r R_e^2 A^2}{16 \pi R^4} 10^{-\alpha R} \quad (3)$$

where  $\omega_a$  is the transmitted acoustic power;  $\gamma_r$  is the concentration coefficient of radiation;  $R_e$  is the effective (equivalent) radius of the target, i.e., a relative quantity which characterizes the reflecting properties of the target;  $A$  is the anomaly factor which characterizes the effect of refraction on signal intensity;  $\beta$  is the space attenuation of signals;  $1/16 \pi R^4$  is a value which characterizes the

widening of the wave front with distance (during both forward and inverse propagation of signals); and  $R$  is the target range.

The noise intensity is determined by means of the following formula

$$I_n = \frac{Q_n}{f \Delta f \gamma_n} \quad (4)$$

where  $Q_n$  is a dimensional factor which indicates the degree of dependence of noise on frequency;  $f$  is the sonar operating frequency;  $\Delta f$  is the bandwidth of the receiving channel which is determined by taking into account the Doppler effect;  $\gamma_n$  is the concentration coefficient during reception. By placing the values given in (2), (3), and (4) into the equation (1) one may obtain an expression for determining the operating range of a sonar.

All the factors which determine the operating range may be divided into several groups. The largest group consists of the following hydroacoustic equipment parameters: the radiated acoustic power,  $\omega_a$ ; concentration coefficients,  $\gamma_T$  and  $\gamma_n$ ; operating frequency,  $f$ ; bandwidth,  $\Delta f$ ; the averaging time,  $T$ ; and the recognition coefficient,  $k_d$ .

One may also include in this group the intrinsic noise level. A separate group may consist of the following factors which characterize the water medium in which acoustic signals are propagating: space attenuation,  $\beta$ ; the anomaly factor,  $A$ ; and the acoustic noise level (reverberation and sea noise). Finally, an important part is played by those factors which characterize the acoustic properties of the target. This group includes the effective (equivalent) radius of the target  $R_e$ . The radius is a relative quantity which indicates the size of an imaginary sphere which reflects signals with the echo signal intensity equal to the intensity of signals reflected by an actual target of any configuration.

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#### The Optimal Frequency Concept.

All factors which determine the operating range of a sonar do, to one degree or another, depend on frequency. Some of them ( $\gamma_T$  and  $\gamma_n$ , for example) help to increase the range with an increase in frequency while others ( $\beta$ , for example) help to decrease it. The conflicting effects of various factors on the operating range result in the existence of the so-called optimal frequency for each operating range. The optimal frequency makes it possible to achieve the required range  $R$  with a minimal transmission power and other constant parameters of a sonar (Fig. 33).

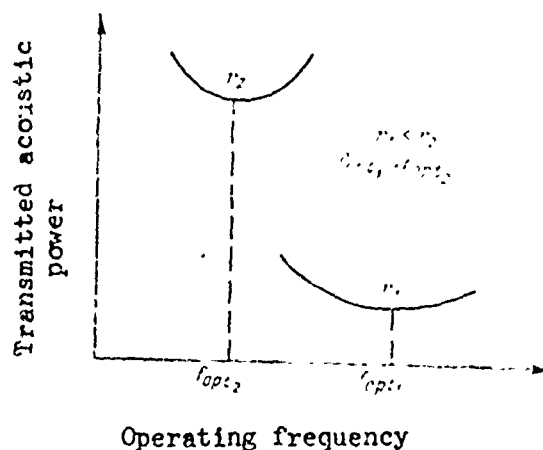


Fig. 33. Curves showing the relationship between the transmitted power and frequency with other sonar parameters being constant.

It is determined by substituting into the range formula all its component quantities in the form which reflects their frequency dependence, and by testing the function obtained for maximum and minimum points. For sonar operation

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$$f_{\text{opt}}(\text{kHz}) = 39/R_{\text{km}}^{2/3}$$

As it is seen from the formula, the greater the required range  $R$ , the lower is the optimal frequency. It should be noted that the relationship between the parameters which determine the operating range and frequencies may, in certain cases, be different. The numerical coefficient in the formula for determining the optimal frequency will change accordingly. However, the general nature of the operating range dependence on frequency will be preserved.

The optimal frequency concept remains also valid for other hydroacoustic devices. Thus for the underwater sound communication devices

$$f_{\text{opt}}(\text{kHz}) = 62/R_{\text{km}}^{2/3}$$

#### Amateur Sonar for Underwater Swimmers.

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The relative simplicity of the step-by-step scanning sonar attracted attention of amateurs. The design of a simple and miniature sonar for underwater swimmers was developed by amateurs V. Il'ichev and M. Svin'in in 1965. It may be expected that the sonar, which combines both simplicity and, in fact, a highly professional degree of

engineering and design sophistication, will attract attention of other amateurs. It seems, therefore, advisable to acquaint the reader briefly with the design and construction of the sonar, thinking that those who will become interested will refer to the thorough and skilled description of the equipment offered by its authors\*.

\*V. Il'ichev and M. Svin'in. A Sonar for Underwater Swimmers; IN: "Sportsmen-Podvodnik", Collection of Articles, No. 18, LOSAAF Publishing House, Moscow, 1968, pp. 50-66.

The fact of the occurrence of the amateur hydroacoustic equipment does, in itself, indicate that a new and interesting area of utilization of their abilities is being opened for skilled radio amateurs. We like to think that, with the development of boating and underwater sport, amateur building of various hydroacoustic devices in our country will expand.

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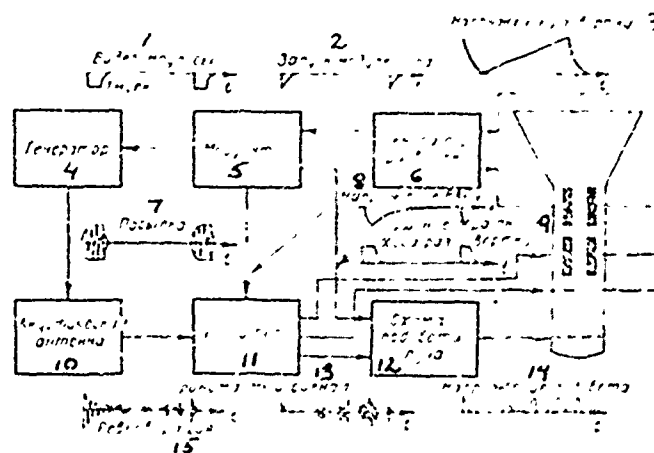


Fig. 35. Block diagram of the amateur sonar  
 (1) video pulses; (2) triggering of the modulator; (3) scan voltage; (4) oscillator; (5) modulator; (6) scan oscillator; (7) transmission; (8) automatic time gain control; (9) quenching of the inverse scan; (10) acoustic antenna; (11) amplifier; (12) beam intensifier circuit; (13) received signal; (14) beam intensifier voltage; (15) reverberation



The sonar circuit, its design, and the basic signal parameters were selected by taking into account the purpose of the sonar which was to insure underwater observations by underwater swimming sportsmen. The problem was to develop a simple and inexpensive, small, lightweight device capable of being built by amateurs. At the same time the device should be able to detect underwater obstacles at a distance of several dozens of meters and be able to determine direction and distance to the target detected. The authors selected a pulsed sonar with the best possible method of direction finding and signal recording on a CRT screen. The latter is also used in the determination of the target range and direction. The authors abandoned the idea of signal listening probably because of lack of the required hermetically sealed telephones with bone conduction. Figure 35 shows a block diagram of the sonar.

The sonar uses an acoustic antenna which was made from a round barium titanate plate 8mm in thickness and 120mm in diameter (Fig. 36).

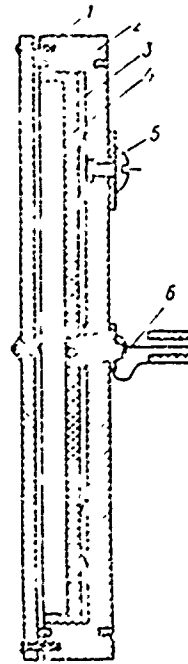


Fig. 36. Construction of the acoustic antenna used in the amateur sonar. (1) diaphragm; (2) housing; (3) barium titanate plate; (4) foamed plastic shield; (5) screw-type plug; (6) output.

Both sides of the plate are silver coated and used as tuned circuit plates. The round plate was placed in a hermetically sealed housing made of aluminum whose front wall is the diaphragm. The non-radiating side of the transducer plate which faces the sonar was shielded by means of foamed plastic. The transducer body is filled with capacitor-grade oil which insures electric insulation of plates and exerts an acoustic load on the plate approximately equal to the water load.

The antenna has a narrow-beam radiation pattern of the order of  $30^\circ$ . Such a pattern, with a small antenna, could be achieved only by utilizing very high frequencies. The operating frequency, therefore, was made 304KHz which exceeds by many times the frequency used in shipboard sonars. This frequency was also the resonant frequency of the transducer plate. Because of the required short operating range, strong attenuation of the acoustic energy which occurs at such a high frequency does not play any important part.

The basic circuit shown in Fig. 37 gives a rather complete picture about the Il'ichev and Svin'in sonar.

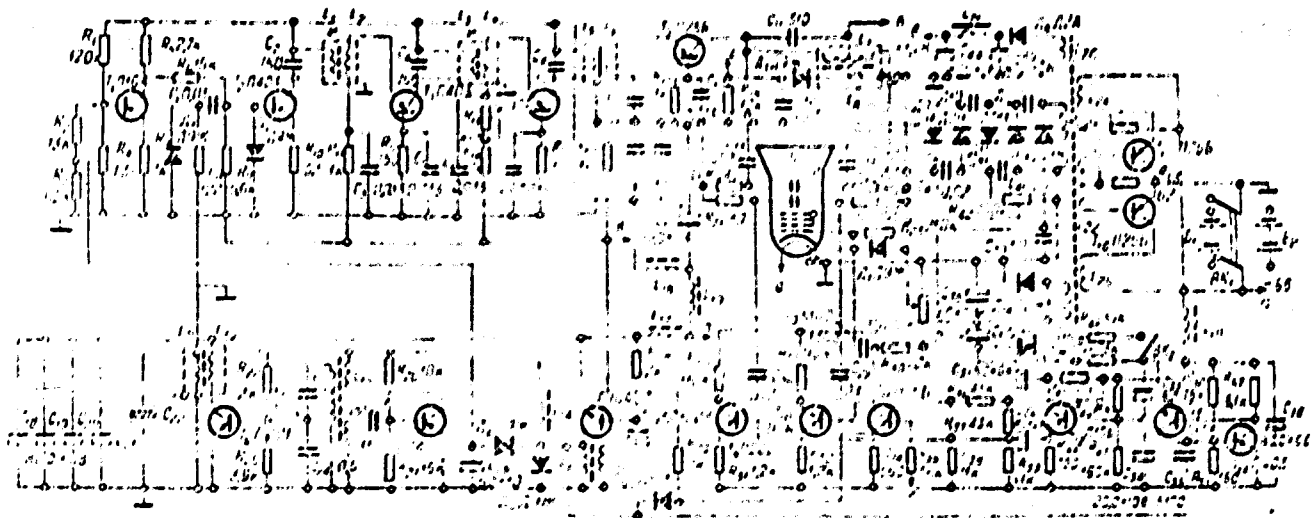


Fig. 37. Basic Circuit of the Amateur Sonar.

T<sub>1</sub> - automatic gain control stage; T<sub>2</sub>, T<sub>3</sub>, and T<sub>4</sub> - h-f amplifiers; T<sub>5</sub> - output stage; T<sub>6</sub> - power amplifier; T<sub>7</sub> - master oscillator; T<sub>8</sub> - modulator; T<sub>9</sub>, T<sub>10</sub> - amplifier; T<sub>11</sub> - video amplifier; T<sub>12</sub> - invster stage; T<sub>13</sub>, T<sub>14</sub> - saw-tooth oscillator; T<sub>15</sub>, T<sub>16</sub> - voltage converter.

The saw-tooth oscillator provides for linear beam scanning on the CRT screen. The scan duration is determined by the time interval between the successive transmissions. For sonars with dial ranges of 0-10m and 0-40m, the scan duration is 13.5 and 53msec, respectively. The scanning voltage insures scans 40--45mm in length on the CRT screen. The scanning voltage is applied to the deflecting plates of the tube so that the swimmer could see the beam moving along the vertical. At the end of the scanning cycle, a negative peaked pulse is generated which triggers the modulator. /88

The modulator is a delay blocking oscillator which generates pulses 0.9msec in duration. These pulses are used for triggering the high-frequency oscillator, for charging the capacitor in the automatic time voltage control circuit, which will be discussed later on, and for quenching the CRT beam during transmission. Modulation pulses trigger the high-frequency oscillator which generates transmission pulses 1msec in duration with a pulse-modulated frequency of 304KHz. This oscillator consists of a transformer-coupled master oscillator and a power amplifier. The output power of the oscillator is about 1.5w. For dial ranges of 0-10m and 0-40m the rate of transmission is 75 pulses/sec and 19 pulses/sec, respectively. After the transmission of each pulse, the oscillator cuts out and does not interfere with the reception of the echo signal.

During reception, the echo signal is fed to a four-stage high-frequency amplifier. The first amplifier stage performs the automatic time gain control. This control is related to the special operating feature of the hydroacoustic system and it is required of all active sonars. We should, therefore, discuss the control function in greater detail. The main points of the reverberation phenomenon were considered earlier. Let us recall that reverberation, which attenuates in time exponentially, interferes strongly with the reception of echo signals (Fig. 38). /89

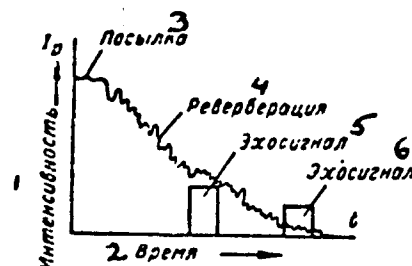


Fig. 38. Masking effect of the reverberation noise  
(1) intensity; (2) time; (3) transmission; (4) reverberation; (5) echo signal; (6) echo signal

Since reverberation accompanies each transmission of acoustic signals and its frequency is that of transmissions, it enters freely the receiver-amplifier channel. This noise deafens the sonar operator and dulls his hearing; it lights electron indicators when it reaches them. One, therefore, should take special measures to eliminate it. The use of an automatic time-gain control circuit is an effective measure for suppressing reverberation.

The principle of operation of the circuit is as follows. During transmission, a capacitor is charged to a voltage whose magnitude can be controlled. The capacitor voltage determines the degree of control. In this case, the capacitor is charged by pulses coming from the modulator. Voltage from the capacitor is applied to the controlled stage (the amplifier stage) in the form of negative bias. The gain of the stage is minimal with the capacitor fully charged. Exactly at this time a maximum reverberation signal arrives at the amplifier input. After the end of transmission, the capacitor begins discharging and the gain of the controlled stage increases. At the same time reverberation undergoes attenuation. The discharge circuit parameters are selected so that the gain increase and reverberation attenuation follow approximately the same pattern. The reverberation level at the amplifier output will remain the same regardless of changes in this level at the input (Fig. 39). The automatic time-gain control parameters do not change in the given circuit while in more complex circuits the degree of control and the capacitor discharge time may be adjusted by the operator depending on the specific conditions.

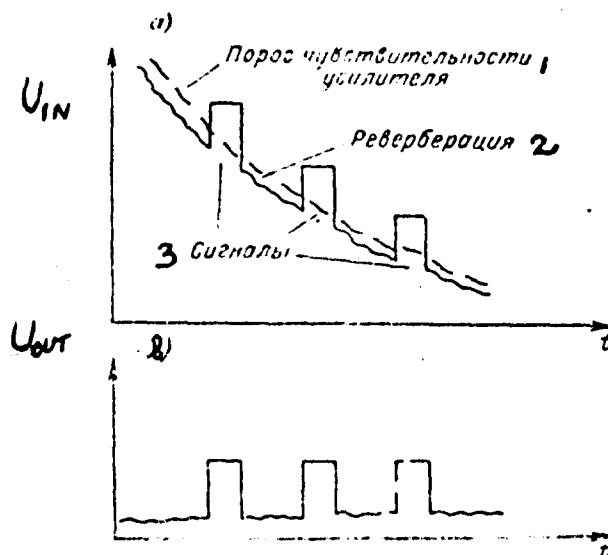


Fig. 39. Reverberation suppression by means of an AGC circuit  
a - amplifier input voltage; b - amplifier output voltage;  
1 - amplifier sensitivity threshold; 2 - reverberation;  
3 - signals

The circuit is also equipped with a manual gain control. 10

The next three stages amplify the signal to a level which insures its reliable display on the indicator screen. The amplifier output pulses are fed to CRT deflecting plates. The maximum amplitude of the blip on the screen reaches 13mm. At the same time, the demodulated signal is amplified and fed to the CRT control grid, thus effecting intensification of the beam.

The power supply consists of 3.5 ampere-hour storage batteries (STs 5-3) which insure a continuous 7-8 hour operation of the sonar. The power supply voltage is 6v and current 850ma. The power supply includes two batteries with four series-connected cells in each battery. One battery is an operating battery while the other is a stand-by battery. The swimmer may switch batteries on and off if one of them breaks down. A semiconductor converter which produces voltages required for the operation of the sonar is connected to the storage battery.

The construction of the sonar is shown in Fig. 40.

Fig. 40. General view of the amateur sonar with the housing removed.  
1 - acoustic antenna; 2 - indicator screen; 3 - range switch;  
4 - power supply cutoff switch; 5 - focusing; 6 - brightness control; 7 - scanning circuit components; 8 - voltage converter components; 9 - storage battery

The sonar is placed in a cylindrical waterproof housing 130mm in diameter and 340mm in length. All parts are mounted on three plates made of laminate bakelite plastic. An acoustic antenna serves as the front cover of the housing. The back cover is made of transparent plastic and the swimmer observes the screen through it. The housing, which is a duralumin tube, contains three handles for power supply switching, for adjusting gain, and for changing the operating range.

The experience gained in the operation of the sonar confirmed that the selection of the circuit and design of the device was proper. Thus, for example, a standard orientation device used in the underwater sport, i.e., a wooden prism 4m in length with a cruciform cross-section and with sides 20cm in length each was, under favorable conditions, detected at a distance of 70m. Under unfavorable conditions, the distance did not drop below 10-15m, i.e., it exceeded considerably the range of visual detection of the orientation device.

The sonar could detect a swimmer and a steel cable 6mm in diameter at a distance of 30-40m while at a distance of 10-15m, it detected fish 20cm in length. It would be difficult to detect such a fish visually at this distance even in air. It may be, that precisely this figure will attract attention of many amateur fishermen to hydroacoustics.

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#### Azimuth Search Sonar.

A block diagram of an azimuth search sonar is given in Fig. 41. Even though many of its elements have names similar to those used in a step-by-step search sonar, their construction and operation are somewhat different.

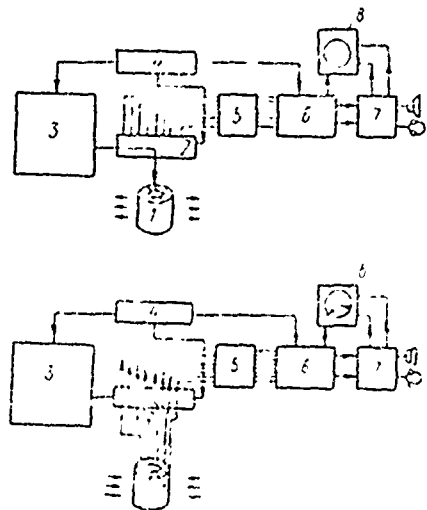


Fig. 41. Block Diagram of an Azimuth Search Sonar.  
1 - acoustic antenna; 2 - switching circuit; 3 - oscillator;  
4 - control panel; 5 - preamplifiers; 6 - azimuth search  
switching circuit; 7 - amplifier; 8 - indicator.

These sonars use cylindrical acoustic antennas which consist of separate transducers. The number of transducers (sections) varies and it may be as high as several dozens in the present day sonars. During transmission, all the transducers operate in parallel and they are driven in-phase by an oscillator. The antenna performs radial oscillations and operates as a unit. The entire surrounding space in the observation plane is irradiated uniformly with acoustic energy. During reception each transducer, being a non-directional acoustic receiver, operates independently. The radiation pattern formation is achieved artificially. During transmission, the switching circuit connects all the antenna sections to the oscillator simultaneously and during reception, it connects them separately to the amplifier.

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The oscillator performs the same function as the oscillator of the step-by-step sonar. However, since it irradiates the entire surrounding space, its power is very high -- of the order of tens and sometimes hundreds of kilowatts. It should be noted that, as a rule, sonars regardless of their scanning methods use pulse oscillators with storage circuits. During the prolonged intervals between transmissions, electrical energy from the power supply is stored in special capacitors. During transmission, these capacitors are discharged rapidly and high-power oscillations are generated. Since the interval between transmissions, which lasts several seconds, is much longer than the duration of the pulse, measured in several tens of milliseconds, the average power consumption of the oscillator becomes relatively low.

During reception, signals from the antenna section outputs are first fed to preamplifiers which increase the signal level to a value necessary for subsequent transformations. Since the antenna sections are nondirectional, the receiving channel of the sonar contains special circuits for forming the radiation pattern. There are two methods which are used rather widely for forming radiation patterns and scanning the surrounding space.

Thus, a pattern rotating rapidly in the plane of observations may be formed in the simplest way. The speed of rotation of the pattern should be such that its lobe completes one full revolution during the existence of the echo signal. Under such conditions, the echo signal enters the receiving channel regardless of the direction from which it arrives. The radiation pattern is formed electrically using delay circuits. Each time it participates in the radiation pattern formation, a group of antenna sections is switched to delay circuits. The idea of this method of forming radiation patterns was considered in detail in the preceding chapter.

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Rapid switching of the antenna sections (the speed of rotation of the radiation pattern lobe is several thousand rpm) is carried out by a contactless circular-scan capacitance commutator. The capacitance commutator is a hollow drum which contains plates which are used as stator plates and which are placed uniformly along the generatrices on the inside surface of the drum. The number of plates corresponds to the number of the antenna sections. A cylindrical rotor revolves inside the stator. The outside surface of the rotor also carries plates which are connected to the terminals of the delay circuit placed inside the rotor. During rotation, the rotor plates pass successively under the stator plates forming transfer capacitances through which signals from the antenna sections pass to the delay circuit. The radiation pattern formed by the delay circuit rotates in accordance with the rotor plates.

Let us note that usually not all the antenna sections but only those facing the echo signal participate in the formation of the radiation pattern. The remaining antenna sections are shielded from signals by the construction elements of the antenna and their use offers no practical interest. In order to economize on the delay circuit elements and the elements of other circuits, only that group of antenna sections which is located within a  $120^\circ$  sector is utilized in the formation of the receiving radiation pattern. During rotation of the rotor, one antenna section, located along the direction of rotation, is switched on at a time continuously while one other section, located on the opposite side, is switched off. The number of the antenna sections connected to the delay circuit always remains constant while the sections themselves change continuously. This change results in the rotation of the lobe and the successive scanning of the area. A schematic diagram of the receiving channel with the capacitance commutator is shown in Fig. 42.

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The described method of receiving signals has a significant disadvantage. Since the radiation pattern lobe makes one or several revolutions per unit of time equal to the duration of the transmission, signal reception is carried out only during the time when the radiation pattern is directed toward the target. At the next instant, the radiation pattern direction changes and the reception of signals stops even though signals continue coming to the antenna. The narrower the radiation pattern, the less amount of the signal energy arrives at the sonar receiving channel. Hence, utilization of the signal energy becomes inefficient. Therefore, the receiving channel construction should be based on a different principle.

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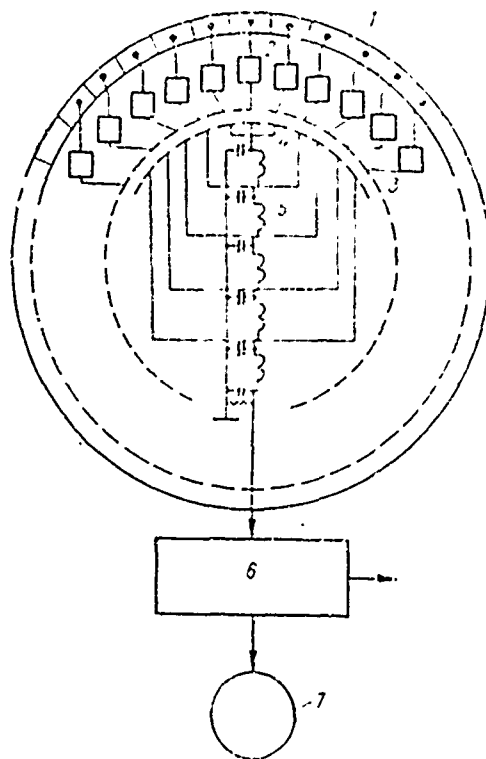


Fig. 42. Schematic Diagram of the Sonar Receiving Channel with the Capacitance Commutator. (1) acoustic antenna sections; (2) preamplifiers; (3) and (4) stator and rotor plates; (5) delay circuit; (6) amplifier; (7) azimuth search indicator.

The ever present radiation patterns which are called "statically formed patterns" are formed in the observation plane. The number of them may be equal to or greater than the number of antenna sections. The major axis of each pattern has its own direction and all of them are located around a circle. Thus, the observation plane is divided into a number of sectors by means of radiation patterns. Scanning is carried out by successive switching (interrogation) of channels and connecting them to the indicator. The receiving channel thus becomes a multichannel system.

Formation of static characteristics is carried out by means of delay circuits with each channel using its own circuit. Each antenna section participates in forming of several adjacent channels. The principle of such channel forming may easily be understood by examining Fig. 43.

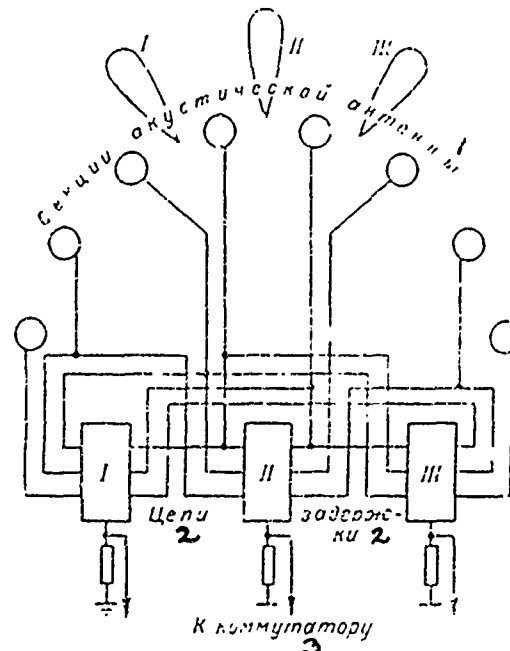


Fig. 43. Principle of lobe forming of static radiation pattern.  
1 - acoustic antenna sections; 2 - delay circuits;  
3 - to the switch.

Each channel contains its own amplifier. An integrating circuit which stores the energy of signals during the time interval between the interrogations is placed at the channel output. A special electronic switch "interrogates" channels in succession by connecting them to the indicator input for a short period of time. Signals are displayed on the CRT screen during switching of signal containing channels. With such a scanning method, the signal energy used experiences practically no losses.

With any scanning method used the signal received, after passing through the radiation pattern formation circuits, is fed to a single-channel or a multichannel amplifier with the AGC and automatic time gain control circuits and the detector. Video signals are applied to a circular scan indicator. This indicator uses helical scanning which is typical for hydroacoustic devices. The beam rotates synchronously with the rotation or switching of the radiation pattern.

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It also moves radially from the center of the CRT screen to the periphery with a speed proportional to the speed of sound. At the time of arrival of the signal, a bright spot is observed on the screen, which uniquely determines the coordinates of the detected target. For reading the coordinates an electronic sight line, i.e., a luminous vector is formed one end of which is brought to the target mark by the operator. The direction of the electronic sight line determines angular coordinates while its length determines the target range (Fig. 44).

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Sonars of various types are widely used by navies of all countries for carrying out observations of the underwater situation.

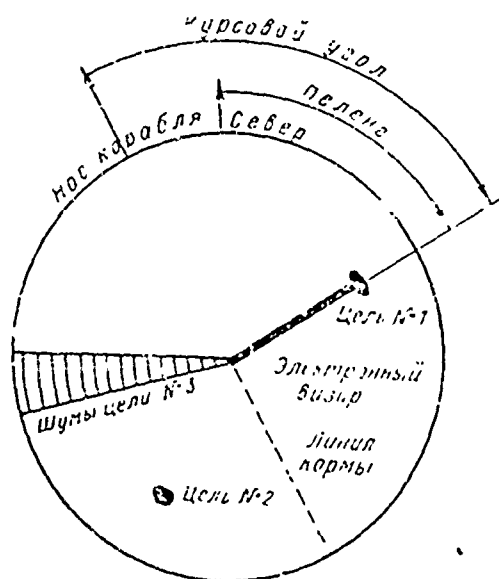


Fig. 44.

### Frequency-Modulated Continuous-Wave Sonar.

In order to get acquainted with the construction and operation of the frequency-modulated continuous-wave sonar, let us consider one type of foreign-made sonars which is intended for use by underwater swimmers.\*

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\*Electronics, No. 52, Dec. 1961, pp. 37-49

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The purpose of the sonar determined its structural simplicity, small size, and weight. All the components of the sonar are placed in a semi-spherical housing with two handles for carrying the device (Fig. 45). Only two pairs of waterproof headphones are outside of the sonar housing. One pair is used by the swimmer carrying the device while the other (the remote headphones) is used by a second person swimming right beside. The sonar can operate in two modes, an active or the main mode and passive, the auxiliary mode. The passive mode is used for finding the direction of the special hydroacoustic beacon or some other signal source. The sonar range in the active mode is 35-40m while that in the passive mode depends on the signal source power.

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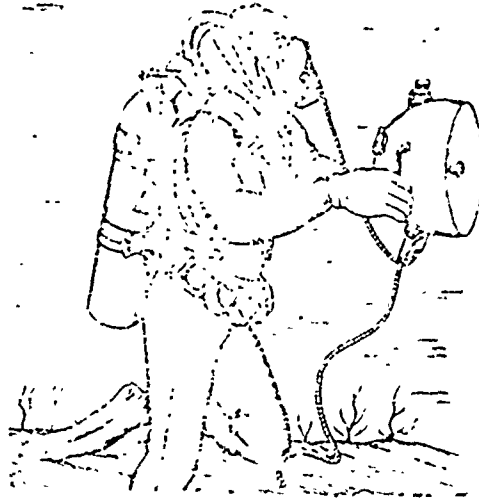


Fig. 45. Underwater swimmer with a portable sonar.

A block diagram of the sonar is shown in Fig. 46.

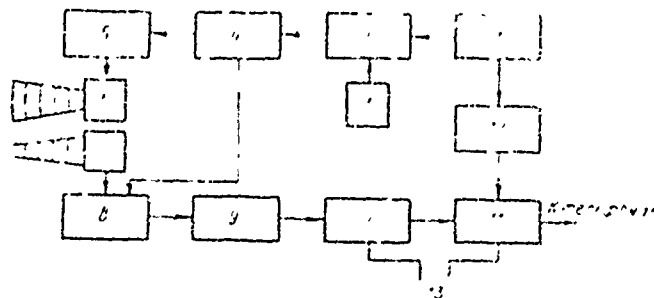


Fig. 46. Block diagram of a frequency-modulated continuous-wave sonar.  
1 - saw-tooth oscillator; 2 - frequency modulator; 3 - manual frequency control elements; 4 - buffer stage; 5 - power amplifier; 6 - transmitting antenna; 7 - receiving antenna; 8 - balanced modulator; 9, 10, 11 - amplifiers; 12 - quenching pulse amplifier; 13 - leak detector

Since both radiation and reception of signals are simultaneous and continuous, the system uses a separate transmitter and receiver which together form a single acoustic antenna. The front housing cover, which has a concave spherical shape, is used as an antenna reflector. The reflector focuses both radiated and received signals and forms the radiation pattern. Transducers in the form of a tube made from barium titanate rings are placed along the axis of the reflector. The transmitter and receiver contain six and eight rings, respectively. The individual rings are insulated by means of rubber gaskets. The entire transducer is placed in a solid insulating rubber jacket. /100

The transmitting channel consists of a saw-tooth oscillator whose period (frequency) is determined by the range of the sonar. Provision is made to operate the device in three range intervals: 0-6m; 0-15m; and 0-36m. The oscillator voltage controls the operation of a frequency modulator whose output signal frequency follows a saw-tooth pattern. Under passive operating conditions, the frequency modulator operates as a frequency mixer which makes it possible to monitor high-frequency signals. The operating frequency of the device is between 30 and 40KHz and it can be adjusted by the operator.

The signal generated is fed to a power amplifier through a buffer stage and then sent to the radiator and the receiving channel. In this channel, the signal is used for producing the instantaneous difference frequency.

The transmitting channel of the sonar should insure linear time dependence of the radiated frequency during changes in ambient temperature (from 0 to 50°C) and power supply voltage. Under these conditions, the frequency should change by not more than 1%. To achieve such a stability, a provision for compensating temperature was made in the transmitting channel.

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The echo signal received is fed to a balanced modulator which forms the sum and difference frequencies for instantaneous values of the received and transmitted frequencies. For determining target range only the difference frequency is used. In the passive mode of operation, the received signal is converted in the balanced modulator into an audio signal with a frequency of 250-2500 Hz. This signal is then transmitted to an amplifier with frequency correction. The amplifier eliminates the difference in the received signal level formed as a result of (1) the attenuation nonuniformity of signal frequency components during the propagation in water and (2) changes in target range. The amplifier also insures constancy of the audio signal. This signal is amplified to a level required for operation of the headphones. A special stage cuts off the amplifier output for the time required by the saw-tooth voltage to accomplish the reverse run.

Penetration of water into the sonar housing may result in breakdown of the device. In order to avoid this, a feedback circuit is used which forms a so-called leak detector. Even several drops of water can short circuit wire electrodes, which are located in the lowest part of the housing, excite the amplifier, and send an alarm signal to the diver.

When operating in the passive mode, the radiator, power amplifier of the transmitting channel, and the quenching stage of the saw-tooth voltage reverse run are disconnected.

The sonar housing is made of cast aluminum. It closes hermetically with the front cover, the antenna reflector. All sonar components use printed circuits. Regular flash light batteries are used for the power supply. The sonar housing contains handles for carrying the device as well as control handles and a compass with an illuminated dial. The compass is used for determining the direction to the target. Changes in target range, i.e., its increase and decrease, are determined by the diver by noting the changes in pitch of sound signals. The equipment can operate at depths down to 60m. The weight of the sonar does not exceed several kilograms and in water it even exhibits a slight positive buoyancy (about 200g).

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Fig. 47 shows another frequency-modulated sonar for underwater swimmers. The device also operates in both active and passive modes. It may be used at depths down to 200m with an operating range of 100m. This sonar uses solid state and integrated circuits which made it possible to decrease its weight (to 4.5 kg in air and 900g in water) and size (height together with a pistol-type handle, 30cm; width, 12cm; and length, 34cm). /10

Fig. 47. Portable sonar for underwater swimmers.  
(1) control panel; (2) magnetic compass; (3) acoustic antennas; (4) handle; (5) headphone.

The use of dry-cell batteries insures continuous operation for 10 hours in the active mode and for 20 hours in the passive mode. A compass with an illuminated dial is placed on the upper part of the sonar housing. One may assume that such simple sonars which are convenient to use and which are small in terms of size and weight will find a wide application among underwater sport swimmers and professional shallow-water divers.

#### 24. Passive Sonars.

Aside from active sonars which are used in making underwater observations, passive sonars are also used widely. The useful signal for these sonars is noise produced in water during motion of surface ships and submarines as well as during motion and vital activities of sea animals and fish. In spite of the fact that this noise is not deliberately produced and that its power is frequently very low, it can propagate in water at very long distances. Noise produced by different sources differs in terms of its spectrum, rythm, and other characteristic features which make it possible for the operator to determine the source of noise almost without errors. According to one specialist abroad "to confuse noise of a torpedo boat with that of a submarine is as difficult as to confuse noise of an aircraft with that of a cab. Experienced operators know how to recognize

passing ships by the nature of their noise in the same way as they recognize their acquaintances by their voice". It should be noted that shipbuilders struggle energetically with ship noise and, particularly, submarine noise. However, passive sonars are also being developed together with new methods of separating useful noise from the background of chaotic noise interferences. According to literature published abroad, the modern passive sonars make it possible to detect ships at a distance of 200 km and longer. The distance at which such noise would be audible in air would be tens and hundreds times less.

As a rule, passive sonars are used by submarines. This can be explained by the fact that noise of submarines is lower than that of surface ships and, therefore, the level of natural acoustic interferences on a submarine is lower. Since surface ships produce considerably more noise than submarines, one can detect a surface ship from a submarine at a considerably greater distance than a submarine from a ship. The construction of passive sonars is a lot simpler than that of active sonars.

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Passive sonars do not contain any bulky transmission channels which consume a large amount of power. However, they may include certain components which are not used in active sonars. A block diagram of one passive sonar type is given in Fig. 48. Its basic operating features are as follows.

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The acoustic antennas of passive sonars should be able to receive very weak low-frequency signals. The size of these antennas therefore is usually very large and the antennas consist of a great number of receiving sections. These sections may be placed so as to form a cylinder, sphere, ellipse, circle, straight line, etc. The shape of the antenna depends largely on the way it may be placed on a submarine.

Weak signals from the receiving sections are fed to preamplifiers the number of which corresponds to the number of the receiving sections. An electric compensator with a delay circuit is used for forming and rotating the directional pattern. If direction finding is carried out by the phase meter methods, the compensator is made with two channels; it forms two lobes, a right lobe and a left lobe. Rotation of the compensator may be controlled either manually by the operator or automatically by means of a target tracking control circuit.



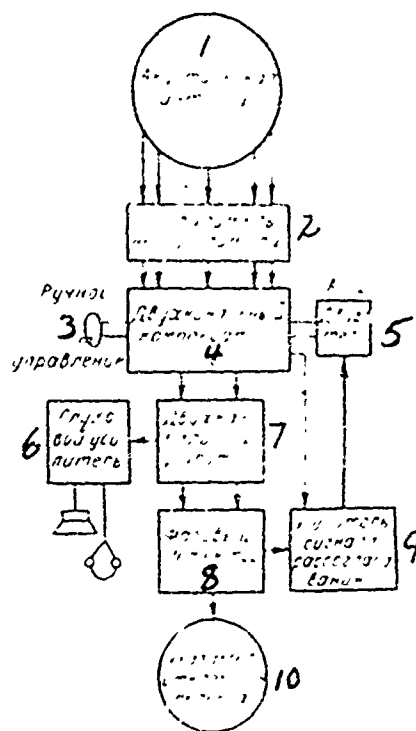


Fig. 49. Block diagram of a passive sonar.  
 1 - acoustic antenna; 2 - preamplifiers; 3 - manual control;  
 4 - two-channel compensator; 5 - automatic target tracking  
 circuit motor; 6 - acoustic signal amplifier; 7 - two-  
 channel amplifier; 8 - phase detector; 9 - error signal  
 amplifier; 10 - direction finder indicator.

From the compensator, the signal is fed to a two-channel amplifier. In contrast with active sonars which operate at fixed frequencies, passive sonars are wide band devices. The amplifier can be tuned to the required frequency band; it is also capable of changing the passband when selecting optimal conditions for observation depending on specific requirements.

For determining bearing, an electronic indicator which is called the direction finder indicator is used. By observing signal changes on the indicator screen, the operator turns the directional pattern until it coincides with the direction toward the target. At the time of coincidence, the operator takes readings from the compensator dial. A phase-sensitive detector or some other similar device may be connected to the output to the two-channel amplifier. The detector generates d-c voltages proportional to the phase shift of acoustic waves arriving at the right and left channels. With a zero phase shift, the detector output voltage is zero. With other phase shift values, voltage signals with amplitudes and polarity corresponding to these values would appear at the detector output. These error signals operate the control system. After amplification, they are fed to the automatic target tracking circuit. This circuit actuates a servomotor which turns the drum of the electric compensator and hence rotates the directional pattern. With the approach of the axis of the pattern to the direction toward the target, the signal phase shift decreases together with a decrease in the error signal. When the directional pattern axis coincides with the target direction, the phase shift and the error signal become equal to zero and the motor stops. The feedback components in the control system insure a smooth operation and prevent the occurrence of undamped oscillations. As the direction of the target changes, the control system of the automatic target tracking circuit smoothly rotates the compensator. During automatic tracking the function of the operator reduces to monitoring the automatic target tracking circuit by watching the signal on the indicator screen. Passive sonars are used in both the military and the civilian national economy.

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#### 23. Underwater Telemetry

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The diverse information obtained in the course of underwater research has to be transmitted to ships, shore stations, and other requesters who are frequently considerably distant from the sources. Wire transmission of information from beneath the water is expensive and inconvenient, particularly during communications with deepsea or travelling objects; by radio links, it is simply impossible due to the tremendous attenuation of electromagnetic waves in the water. And this is where hydroacoustics comes to the rescue. Sound telemetry, that is, the transmission over distance of data on any controlled parameters in the form of hydroacoustic signals, has acquired increasing significance recently.

The study of sounds made by marine life and fish is of tremendous scientific and practical interest. Man is successfully using his knowledge in the exploration of areas of fish and marine life concentration, for example, in exploring for the Kamchatskiy crab, and also for classification, that is, for determining species of marine life. The assumption is being expressed that by emitting into water earlier recorded calling sounds made in the mating season or during feeding, it is possible to attract such fish like the sciaenidae and herring, and other commercial species to the fishing site. Investigations by Japanese specialists have indicated that fish react to underwater signals to a distance of 1,000 km. It is also suggested that it would be possible to drive some species of marine life, for example sharks, from certain areas by creating either noises which are unpleasant for them or sounds made by their enemies. In the very same manner, it is possible of herd fish into trawls and other fishing equipment.

Biological research related with the study of dolphins, the most puzzling animals of the seas and oceans, has gained considerable significance. Initial interesting results have already been obtained. Scientists have established that various hydroacoustic signals are highly important in the activity and mutual contact of dolphins. It has turned out that the dolphin has two, and according to some observations even three, sound sources enabling the generation of vibrations with frequencies of 150 Hz to 120 and greater kHz and of varying shape (from rectangular pulses to a right sinusoid).

The sounds made by dolphins vary in frequency and amplitude within a wide range and resemble, in the opinion of different observers with an obviously uncommon imagination, whistling, clicking, chirping, squeaking, humming, twittering, grumbling, squealing, cheeping, and even bellowing and mewling. From a scientific viewpoint, the interest is for less picturesque and more accurate reports of the results of investigating dolphin signals obtained through the analysis of the frequency composition of sounds and the distribution of the frequency components of the spectrum with respect to time and amplitude using special radioelectronic equipment. /129

Echo location plays an exceptionally important role in the life of dolphins. As has been discovered, the "echo locator" of a dolphin is considerably superior in its capabilities to even the most advanced sonars developed by man. The "echo locator" of a dolphin makes it possible to emit and receive sound vibrations in a wide frequency range, to vary the frequency of these signals, to change the emission directivity from an all-directional to a narrow beam, and to so combine the work of its several sound sources in order to receive vibrations of a complex shape which are modulated in amplitude and frequency. With the aid of its "echo locator," the dolphin is capable of easily orienting itself in a difficult environment.

Underwater telemetering systems based on hydroacoustic principles are widely being applied both in the Navy during underwater weapon testing and in solving a diversity of economical and research problems. For example, telemetering systems are being used in the fishing fleet for transmitting information from a light probe to a ship concerning the operation of a trawl, the expansion of its opening, the quantity of fish in the trawl, and the depth of its course. With the aid of telemetering systems, it is possible to observe the behavior of fish and marine life "tagged" with sound transmitters. Telemetering systems /126 make it possible in oceanography to obtain information on the temperature and salinity of water, current velocity, and other parameters of interest to scientists from a variety of sensors placed at various, and very frequently great, depths. Telemetering systems are also employed in the mining of commercial minerals and petroleum at underwater works. Telemetry enables observing the condition of equipment, remotely controlling various apparatus on the sea bottom, and solving many other problems.

Let us briefly examine the principles of operation of the one possible mode of a hydroacoustic telemetering system (Fig. 58). The electric signals coming from the sensors and information sources modulate the frequency of subcarriers produced by special generators. The standard frequencies, which are also used in telemetering systems based on other principles of energy transmission, are normally employed as subcarriers. This makes it possible to use standard signal-shaping elements in the apparatus. Frequency modulated subcarriers enter the generator of the carrier frequency, where a secondary modulation occurs. The carrier frequency is selected based on the propagation characteristics of the acoustic vibrations in water. For example, in the system under question, it is assumed to be 40 kHz. As a result of the double modulation, an FM/FM signal is formed which is also fed to a radiating acoustic antenna. The sensory element and the entire system of the transmitting channel are usually placed on the sea bottom on a deepsea installation or suspended in the water from a cable at a specific depth. /127

The equipment designed to receive the information is above water, e.g., aboard a ship, on a buoy, at a shore station, etc. The signals arriving at the receiving antenna are amplified and sent to the carrier frequency discriminator, where the carrier frequency is demodulated, and upon exit of the signal, the series of modulated subcarrier frequencies are separated. These frequencies are demodulated in the subcarrier frequency discriminators, at whose outlets the original information is separated in the same form it entered the input of the transmitting channel of the telemetering system. The output signal, which reproduces the original information, is recorded by oscillographs, plotters, or any other instruments.

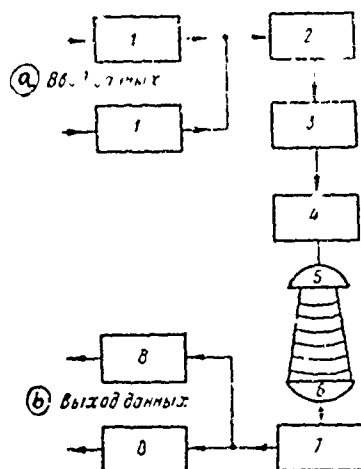


Fig. 59. Block diagram of a hydroacoustic telemetering system.  
 1 - subcarrier frequency generator; 2 - carrier frequency generator; 3 - amplifier; 4 - power amplifier; 5 - transmitting acoustic antenna; 6 - receiving acoustic antenna; 7 - carrier frequency discriminator; 8 - sub-carrier frequency discriminator; a - data input; b - data output.

Some acoustical telemetering systems are capable of simultaneously transmitting digital information from ten different sensors and one telephone conversation. When necessary, the system can be combined with a radio link, i.e., the information coming from beneath the water over an acoustic channel is converted on the surface and transmitted further by a radio transmitter, which makes it possible to considerably increase the range of data transmission.

## 29. Sea Bioacoustics

With the development of hydroacoustics, one of the oldest and most persistent myths, the idea of the sea as a world of silence, was shattered. It is true that individual references concerning "talking fish" and other sounds made by fish and marine life have been encountered as far back as ancient times. Their present study became possible only in recent decades after the emergence of appropriate hydroacoustic equipment. Even a special branch of acoustics has been born: biohydroacoustics, which deals with the study of sounds made by marine life and the interference of hydroacoustic equipment operation originating because of these sounds. Soviet scientists have a distinguished position in the development of hydroacoustics. In 1968, a group of domestic scientists created the unique atlas of "Fish Sounds", and now anyone desiring so can listen to these sounds by using the sound records enclosed with the atlas. /128

For example, in the course of experiments, it was observed that dolphins are capable of almost unerringly differentiate small objects according to their size. Alice the dolphin easily distinguished the larger of two metal balls, one 5 cm in diameter and the other 4.2 cm in diameter. Even with a diameter difference of only 2 mm, the dolphin almost without error selected the larger. This accuracy of echo location is viewed in our day as exceptionally and significantly superior to the accuracy attained by modern existing equipment. In some instances, the echo locator of dolphins also permitted the identification of objects according to the material from which they were made. Research of the echo location of dolphins could not be done without the employment of various hydro-acoustic and other radioelectronic apparatus.

Radioelectronics may play quite an exceptional role in the study of the language of dolphins and the attempts to establish communication between man and dolphins as between intelligent creatures. /130  
Aside from the direct scientific and practical significance of solving this problem, according to the bold assumptions of many scientists, some aspects in the solution of this problem could serve in the future as a foundation in establishing communication with being of distant extraterrestrial civilizations. We should mention in advance that we are not examining here the various and rather complex philosophical and other problems related to an evaluation of the existence of a dolphin's powers of apprehension, language, speech, etc., and will limit ourselves only to a discussion of the radioelectronic support of investigations.

Thus, the initial attempts to establish communication with dolphins have brought encouraging results. Communication was done with the aid of specially developed radioelectronic gear. Two essentially different approaches were used here to solve the problem.

One of the ways was to develop equipment which would make it possible to convert human speech into sounds of far higher frequencies lying within the best audible range for the dolphin, and the high-frequency sounds emitted by dolphins into the far lower frequencies perceptible to man. With such equipment at his disposal, the scientist was then able to direct his attention to the dolphin, who listened to his words converted into a frequency suitable for the dolphin and repeated them in the form in which he heard them. After a reverse conversion, the dolphin's "reply" was heard at human speech frequencies, and the investigator was able to compare the "question" and "reply" and determine how correctly the dolphin perceives and reproduces human speech. By this same method, it was possible to give the dolphin individual commands and to listen to the sounds it emitted independently without previously being addressed, etc.

A block diagram of the apparatus built on this principle is shown in Fig. 59. Human speech was converted by means of a ten-channel vocoder which enabled compressing the speech spectrum. With the aid of band-pass filters, the spectrum of human speech was distributed over ten channels, at whose outlets basic tones were produced from amplified signals. The rectified signals of the basic tones modulated higher frequencies and passed through the band-pass filters which had central frequencies ten times higher than the frequencies of the corresponding basic tones. By this means, the frequency spectrum of human speech shifted upward by an order of one. The high frequency signal which was then obtained was sent to an acoustic antenna after amplification and emitted into the pool where the dolphin is found. The response signals from the dolphin were received by the antenna and converted in a reverse order. With the aid of oscillographs, it was possible to observe the shape of dolphin signals before and after their conversion, while a four-track tape recorder recorded the entire "dialogue" for its subsequent analysis.

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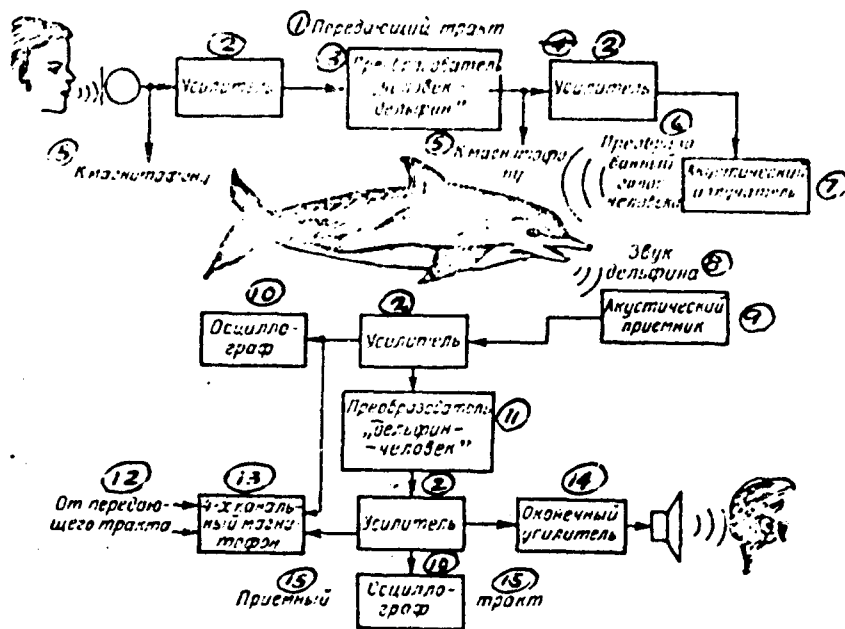


Fig. 59. Electronic conversion of the frequency spectrum of human speech into a region of higher frequencies, and of dolphin sounds into a region of lower frequencies. 1 - transmitting channel; 2 - amplifier; 3 - "human to dolphin" converter; 5 - to tape recorder; 6 - converted human voice; 7 - loudspeaker; 8 - dolphin sound; 9 - microphone; 10 - oscillograph; 11 - "dolphin to human" converter; 12 - from transmitting channel; 13 - 4-track tape recorder; 14 - end amplifier; 15 - receiving channel.

Another experiment used whistles, which are more familiar to dolphins than a converted human voice. A radioelectronic apparatus developed for this purpose (Fig. 60) translated human speech into a certain sequence of whistles at a frequency suitable for the dolphin's perception. The response whistles emitted by the dolphins were in turn converted into artificial words. For signalling, something like an alphabet for this artificial quasidolphin language was developed: to certain phonetic sounds of human speech were assigned specific frequencies of a whistle, for instance, the letter "A" corresponded to a frequency of 7 kHz, the letter "I" to 11 kHz, the letter "R" to 11.5 kHz, etc. A characteristic of the operation of man's speech apparatus was used to convert sounds into whistles. As one knows, the vibration of the vocal cords brings forth a series of sound pulses, which reverberate in the mouth and in the throat cavities of man; in the pulses is introduced a specific sequence of time delays depending on the position of the tongue, lips, etc. This sequence also determines that information which is contained in speech. With the aid of equipment, a determination was made as to the value of the time delay between the moment the vocal cords snap (beginning of pulse) and the moment one of the frequencies in the speech output signal, ranging approximately between 500 and 800 Hz, is emitted. The time delay converted into d.c. voltage with an amplitude proportional to the measured delay value. This voltage flowed to the input of the whistle generator and controlled the frequency it produced. Each delay value was matched by a specific generator frequency. A whistle valve logically ensured their generation only during a specific time interval, given the presence of human voice signals at the input to the apparatus. The amplified whistles were emitted into the water by an acoustical antenna. /133

To transmit the various signals and commands, use was made of artificial words consisting of several sounds comprising the alphabet of the whistles. Thus, for example, the word BAEP stood for the command "begin echo location," BETAP for "swim through the hoop", etc. Response signals--whistles--were converted by the apparatus in a reverse order and induced the formation of sounds of synthesized language. The limitation in the number of usable sounds and words was determined by the human's difficulty in perceiving the dolphin's complex response signals.

In the course of the experiment, it was not only possible to train the dolphin to repeat accurately words spoken to it, i.e., whistles (the trainer confirmed the correctness of a repetition by the word BLYP and gave the dolphin a fish), but also to perform several of the most simple commands. For example, a dolphin named Dash was trained using to distinguish by word command a ball and a hoop floating in the pool. He would swim through the hoop, to the opposite side of the pool, and wait for further "instructions."



Of course, all this is still very far from being able to talk about speech communication. The experiments conducted only show that the dolphin is capable of repeating certain sounds and performing certain commands. There are many other animals capable of doing the same thing. There still remains to the present day an unsurmountable barrier between species. It is necessary to solve many technical problems. Yet man hopes to discover many more secrets of the ocean depths with the "aid" of the dolphin. And there is no doubt as to exceptional role of radioelectronics in this. /134

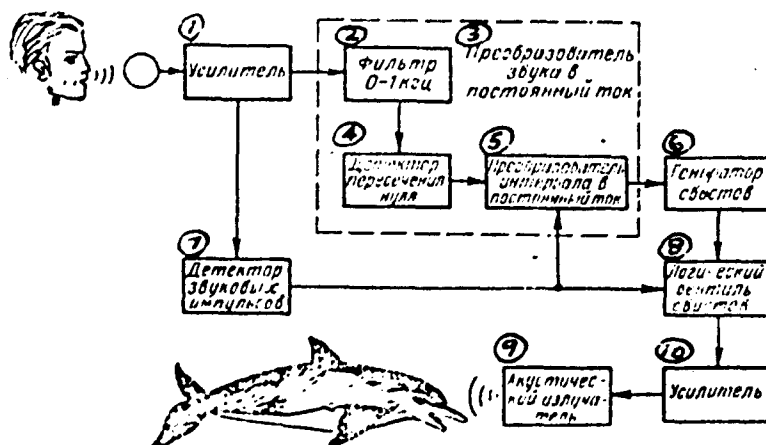


Fig. 60. Electronic conversion of artificial words into whistles with a varying pitch tone. 1 - amplifier; 2 - 0 to 1 Hz filter; 3 - converter of sound into a direct current; 4 - zero intersection detector; 5 - converter of an interval into a direct current; 6 - whistle generator; 7 - sound pulse detector; 8 - logic whistle valve; 9 - acoustic emitter; 10 - amplifier.

### 30. Underwater Ultrasonoscopy

It is well known that of all the sensory organs of man, vision provides the greatest information about the surrounding world. We have the familiar proverb, "it is better to have one look than to listen a hundred times." This proverb is also valid for underwater observation. However, we are already acquainted with the fact that light penetrates under water to only very short distances and that visibility under water rarely exceeds a few meters. Visibility is practically absent in turbid, muddy water and at great depths.

The use of various sources of underwater lighting is advantageous only in a few situations. And at the same time, the most diverse situations are encountered in which it is necessary to see any particular underwater object. By the word "see" we mean first of all, the ability to determine the shape and size of an object, that is, to obtain only part of the information which passes through the eye. Yet even such a limited capability is of tremendous practical interest. Specifically, how to determine the source of an echo signal obtained during sonar: is it a rock, a mine lying on the bottom, or a sunken barrel? How can one distinguish, among the many objects reflecting approximately the same echo signal exactly the one which interests us? It appears that even this problem could be solved with the use of hydroacoustic principles. It is true that in our day the solution of this problem is still within the experimentation stage; but, judging from press reports, the experiment is developing successfully.

The famous Soviet scientist L. D. Rozenberg has given the name of ultrasonoscopy to those methods of obtaining images with the aid of ultrasonics. Let us briefly examine the essence of this phenomenon. The general principle of ultrasonoscopy is similar to that of seeing in light beams. However, the observed object is not illuminated by light but rather irradiated by ultrasound, and the beams, which are reflected from the object and form a sound image of it, are converted into an image visible to the eye. This involves two basic technical problems: obtaining a sound image and converting it into a visible image.

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The difficulty in forming a sound image lies in obtaining the required resolution. Since sound waves are considerably longer than light waves, in order to obtain a high resolution it is necessary to use very high frequencies reaching tens of megahertz. However, even then, resolution does not appear to be sufficiently high. For example, when using ultrasound with a frequency of 4 Mc, as is the case in an actual apparatus, the wavelength in the water amounts to 0.37 mm, that is 740 times greater than the wavelength of visible light. There is a corresponding deterioration of resolution. The sound image of the minute detail of an observed object cannot have dimensions smaller than 1.175 mm. The use of higher frequencies is undesirable for two reasons: it is difficult to produce such frequencies for sound irradiation and the attenuation of ultrasound in water sharply increases when frequency is increased. However, even with the tremendous attenuations at megacycle frequencies, the range of ultrasonoscopy considerably exceeds the range of visibility in light beams.

The difficulty of obtaining a sound image from small objects is associated with yet another phenomenon. If the elements of the reflecting surface are much smaller than the length of the incident wave, a regular reflection occurs in observation of the law "the angle of reflection is equal to the angle of incidence." In this case, the image strikes the objective only when it is in a certain position relative to the observed object, and in the general case, the object may seem invisible. If, however, the elements of the reflecting surface are commensurate with or greater than the length of the incident wave, energy is diffusely reflected and scatters in all directions. It is apparent that even from this viewpoint, it is desirable to shorten the wavelength of the irradiated vibrations; otherwise, small articles or surface elements of an observed object will not be scanned. Thus, in the ultrasonic "irradiation" of any underwater object, it is possible to obtain its sound image which consists of the acoustic pressure distribution in the focal plane of the "sound objective" resulting from the diffuse reflection of acoustic energy from individual surface elements of the object being examined. The degree to which the image corresponds to the object itself will depend on the principles already examined above.

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It then becomes necessary to take this image and convert it into a visible image. This can be done by various methods; however, in underwater ultrasonoscopy, the most suitable method is signal reception employing the principles of acoustic-electrical conversion already discussed above. Normally, the piezoelectric effect is used for converting acoustic signals into electrical signals. The entire system for converting an acoustical image into a visible image is called an electronic-acoustic converter (EAC). The circuit of such a system (Fig. 61) was suggested as far back as 1936 by the well known Soviet acoustician S. Ya. Sokolov.

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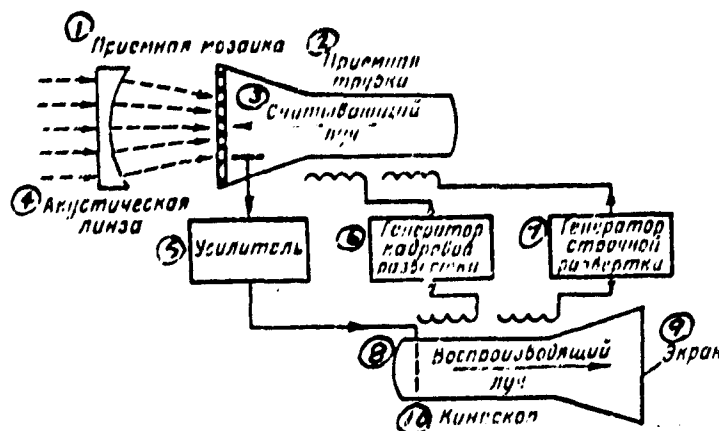


Fig. 61. Simplified diagram of an ultrasonoscope. 1 - receiving mosaic; 2 - receiving tube; 3 - scanning beam; 4 - acoustic lens; 5 - amplifier; 6 - framing generator; 7 - horizontal scanning generator; 8 - reproducing beam; 9 - screen; 10 - picture tube.

An image is focused by an acoustic lens on the receiving surface of a special cathode-ray tube made of piezoelectric ceramics. When a sound image strikes this surface, a static charge is produced on it with a distribution which reproduces the distribution of the acoustic pressures in the image. If the value of this charge is removed with the aid of the electronic beam performing the raster scanning, as in television, then a videosignal will form at the tube outlet. In spite of the apparent simplicity of the idea, the development of a tube involved considerable technical difficulties which were successfully overcome by Soviet scientists. One of the principal difficulties is that the piezoelectric pickup surface of very fine thickness is an element of an electronic tube. In order to provide it with the required strength and to maintain a vacuum, metal electrodes numbering tens, and sometimes several hundred, in a square centimeter are soldered in piezomaterial. These electrodes pass through the glass of the forward wall of the tube. The video signal taken from the receiving tube is amplified and fed to a reproducing cathode-ray tube.

There are also other ideas of image reception. For example, in one such system, the outlet of each individual element of a receiving surface is connected through a photodiode to an amplifier. The photodiodes in turn open in order to interrogate the corresponding element by illuminating them with a narrow beam of light. With such a design for the receiving system, there is no need to develop a vacuum. Consequently, the size of the apparatus can be reduced. As reported in the press, there are already experimental underwater ultrasonoscope systems which make it possible to detect small objects in turbid water at a distance of 10 meters.

The suggestion is being made that in the not too distant future ultrasonoscopes will be fitted on deepsea apparatus and even used by divers.

### Conclusion

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Thus, we have been acquainted with hydroacoustics, one of the fields of modern applied radioelectronics. The entire development of this technology is inseparably linked with man's conquest of the World Ocean. And it is precisely now, when mankind is undertaking the task of totally conquering the depths of the seas and placing at his service all the treasures hidden by the ocean, that extraordinary successes are being achieved in the development of hydroacoustics. The potentials of hydroacoustics are far from being totally realized, and it is possible to anticipate that in the very near future, we will find out many new areas for its application. And present-day uses of hydroacoustics are far from being exhausted by the examples we examined.

Hydroacoustics plays an exceptionally great role in the military. Underwater detection of an enemy and the attack deployment of a submarine from any depth; submarine detection and pursuit by ships; torpedo homing systems, acoustic proximity fuzes, equipping test ranges for underwater weapon research -- this is a far from complete list of the most important areas of application of hydroacoustics in the Navy.

Hydroacoustics is finding increasing wide use in ship navigation by making it possible for ships and submarines to navigate in the most difficult and unusual circumstances. Sound beacons, including those using nuclear energy sources, have appeared on the ocean bottoms. Under-ice and iceberg sonars have opened the way for submarines to navigate under the ice of the Arctic and Antarctic. Doppler hydroacoustic navigation aids are making it possible to continuously calculate the position of a ship with a high accuracy. The mapping of the seabottom has acquired unprecedented dimensions.

The diverse hydroacoustic technology has since long become an indispensable tool for fishermen and scientists studying sea life. It is finding wider and wider use with geologists. Seismic research of seabottom structure, prospecting for commercial minerals and petroleum, and support for the operation for deepsea systems and underwater industries would be impossible today without this technology. Special systems of hydroacoustic reference points and responders maintain with high accuracy the position of floating platforms for drilling superdeep holes in the earth's core.

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Hydroacoustics is increasingly being used also to accomplish such exotic tasks as searching for sunken treasures, in underwater archeology, and even for establishing the fact whether or not the legendary Loch Ness monster exists or for revealing the secret of the City of Kitezh (translit. from Rus.). As we have already seen, hydroacoustic technology is becoming a possession of sportsmen and enthusiasts of water sports.

Among the problems facing mankind, which are expected to be solved in the very near future, are such as the supporting of man's capacity for a long underwater stay, the development of experimental underwater habitats and subsequent colonization of the continental shelf and ocean bottom, and many others. And among the special technology designed to solve these immense problems, a worthy place will be held by the diverse hydroacoustic equipment.

## BIBLIOGRAPHY

### Popular Science Literature:

Karlov, L. B., and Shoshkov, Ye. N. Hydroacoustics in the Military. Moscow, Voenizdat, 1963.

Klyukin, I. I. The Deafened Neptune... Leningrad, "Sudostroyeniye," 1967.

Prostakov, A.. Hydroacoustics in the Navy. Moscow, Voenizdat, 1961.

### Specialized:

Giyges, L., and Sabate, P. Principles of Sea Acoustics. Leningrad, Gidrometeoizdat, 1967.

Stashkevich, A. F. Sea Acoustics. Leningrad, "Sudostroyeniye," 1966.

Tyurin, A. M., Stashkevich, A. P., and Taranov, E. S. Principles of Hydroacoustics. Leningrad, "Sudostroyeniye," 1966.

Prostakov, A. L. Hydroacoustics and the Ship. Leningrad, "Sudostroyeniye," 1967.

Khorton, D. Principles of Sonar. Leningrad, Sudpromgiz, 1961.

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